

## **Research Brief for DOE/IHEA Process Heating Materials Forum**

### **Research Title: High-Temperature Alloys**

**Industry Need:** The process heating systems use a combination of metallic and non-metallic (refractories and ceramics) materials for a broad range of its functional regions including: heat generation, heat transfer, heat containment, waste heat recovery, emission control, materials handling, and sensors and control protection. The specific components in the functional regions can vary from sand and centrifugal castings, sheet material for heat shields and recuperators, wires and rods for heating elements, investment cast or machined nozzles, castable refractories, monolithic and machined ceramic parts, and protective coatings for resistance from specific environments. The component life of process heating components is shortened by a variety of causes. The most important causes include: (1) High-Temperature Creep Strength: limits life by sagging and rupture, (2) Thermal Fatigue: Large temperature gradients between the surface and interior of components cause surface cracking and lead to premature failures; and (3) Corrosion: A broad range of corrosion mechanisms limit the life of the process heating components: oxidation, carburization, nitridation, metal dusting, attacking by halogens, and aqueous corrosion during waste heat recovery.

The payoff in improving materials performance (extending life) for the process heating industry is very significant in energy savings, cost savings, improved product yield, and quality. Transfer rolls for austenitizing furnaces for steel plate are one of the examples for energy and cost savings. In this case, the use of nickel aluminide for transfer rolls eliminates shutting the furnace down on a bi-weekly basis, eliminates the remelting and processing of a fraction of damaged steel inventory, and reduces the energy used in the production of rolls, which require frequent replacement. Any time energy is saved, cost is saved but additional cost savings result from less frequent and shortened downtime, reduced roll inventory needs, reduced need for replacement of rolls, and improved product quality.

**Existing Research:** There has been active research in developing new materials and improving existing high-temperature materials for the process heating industry. Examples include: development of nickel aluminides for transfer rolls for austenitizing furnaces, heat-treating trays and fixtures for carburizing and annealing furnaces, and radiant burner tubes. Development of iron aluminides for nozzles, ingot supports for homogenizing furnaces, heating elements, and for carburization and coking resistance.

There are current activities underway in enhancing the creep strength of H-Series stainless steels, Fe-3Cr-W(V) steels, and high-chromium alloys to further address the process heating-related needs. The existing research activities have close collaboration with many industrial partners including: Bethlehem Steel, Duraloy Technologies, The Timken Company, Delphi, ExxonMobil Chemical Co., Nooter Fabricators, Stoodly Company, Weirton Steel Corporation, Ellwood Quality Steel, Alloy Engineering & Casting Co., Special Metals Corporation, Delphi Automotive, Ametek, Bethlehem-Luken Steel, and AK Steel.

**Proposed Activity:**

Intermetallic Alloys (Ni and Fe Based): Transfer rolls and heat-treating trays and fixtures have been the key applications where the technology has been implemented. These alloys have potential for many other applications including: radiant burner tubes, heating elements, fans, and hearths. Some of the applications are limited for lack of producing defect-free components. Additional work is required on these materials in the areas of: (1) optimizing casting parameters for complex static castings to minimize defects, (2) optimize surface pretreatments that enhance service performance, (3) improve further the high-temperature strength, (4) develop and optimize welding processes during production and repair in service, (5) develop additional mechanical properties, (6) corrosion data on base and weld metal, and (7) explore the use of coatings.

Improve Strength of H-Series Stainless Steels: The existing project is using computational and micro-analytical tools to enhance the properties of currently used H-Series steels such as HK and HP. It will be extremely useful to build on this research to start implementing the steels with improved strength. Such activities will require additional effort in: (1) optimizing casting parameters for the improved alloys, (2) developing mechanical and corrosion properties, (3) weld parameters and weld wire for the new and improved compositions, and (4) production of components for in-plant testing. Effort should also be made to explore if the H-Series concept can be used for wrought products. This will require developing flow stress data at high temperatures and strain rates to determine the deformability of these alloys under production environment.

Alumina Former Alloys: There are both the ferritic and austenitic grades of alloys to which sufficient amounts of aluminum can be added to improve their corrosion protection through the formation of  $Al_2O_3$  on the surface. Such steels have advantage of high ductility than aluminides, which are ordered compounds. A significant effort needs to be devoted in identifying both the ferritic and austenitic compositions with sufficient aluminum for  $Al_2O_3$  formation on the surface. Effort will include: (1) ThermoCalc™ to identify optimum aluminum content for  $Al_2O_3$  formation and for identifying the limit where significant ferrite fraction forms, (2) alloy casting and processing, (3) mechanical and corrosion properties, and (4) weld parameter optimization. Starting basis for this can be Fe-20Cr-4.5Al for ferritic steel and Fe-25Cr-20Ni for austenitic steel. Some background work already exists on these alloys from other programs.

Fe-3Cr-W(V) Alloys: The current activities are devoted to optimizing composition and generating property data to get these alloys in the ASME Pressure Vessel Codes. However, additional effort will be needed including: (1) explore the use of these alloys as cast components. Such applications will require: (a) casting parameter optimization, (b) heat-treatment optimization, (c) mechanical property determination, and (d) welding process parameter development; and (2) Fabricate and test components in the process heating systems. This will require: (a) fabrication of tubes for heat-recovery systems, and (b) fabrication of pipe for steam lines and other components to be identified.

High-Chrome Alloys: These alloys offer excellent corrosion protection under a variety of process heating industry environments. However, for these alloys to find broader applications, additional effort is needed in: (1) optimizing the processing methods for various shapes, (2) corrosion testing, and (3) mechanical properties.

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